Jet Substructures of boosted hadronic tops

Hsiang-nan Li

Academia Sinica

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In collaboration with Yoshio Kitadono

Outlines

- Review of boosted leptonic tops
- Boosted hadronic tops
- Top jet energy profiles
- Conclusion

Kitadono, Li arXiv:1403.5512

Review of boosted leptonic tops

Theoretically easy, but
experimentally hard

Boosted heavy particles

- Heavy particles (Higgs, W, Z, top, new particles) may be produced with large boost at LHC
- Decaying heavy particle with sufficient boost gives rise to a single jet
- If just measuring invariant mass, how to differentiate heavy-particle jets from ordinary QCD jets? How to reveal properties of heavy particles?
- Use different jet substructures resulting from different weak and strong dynamics

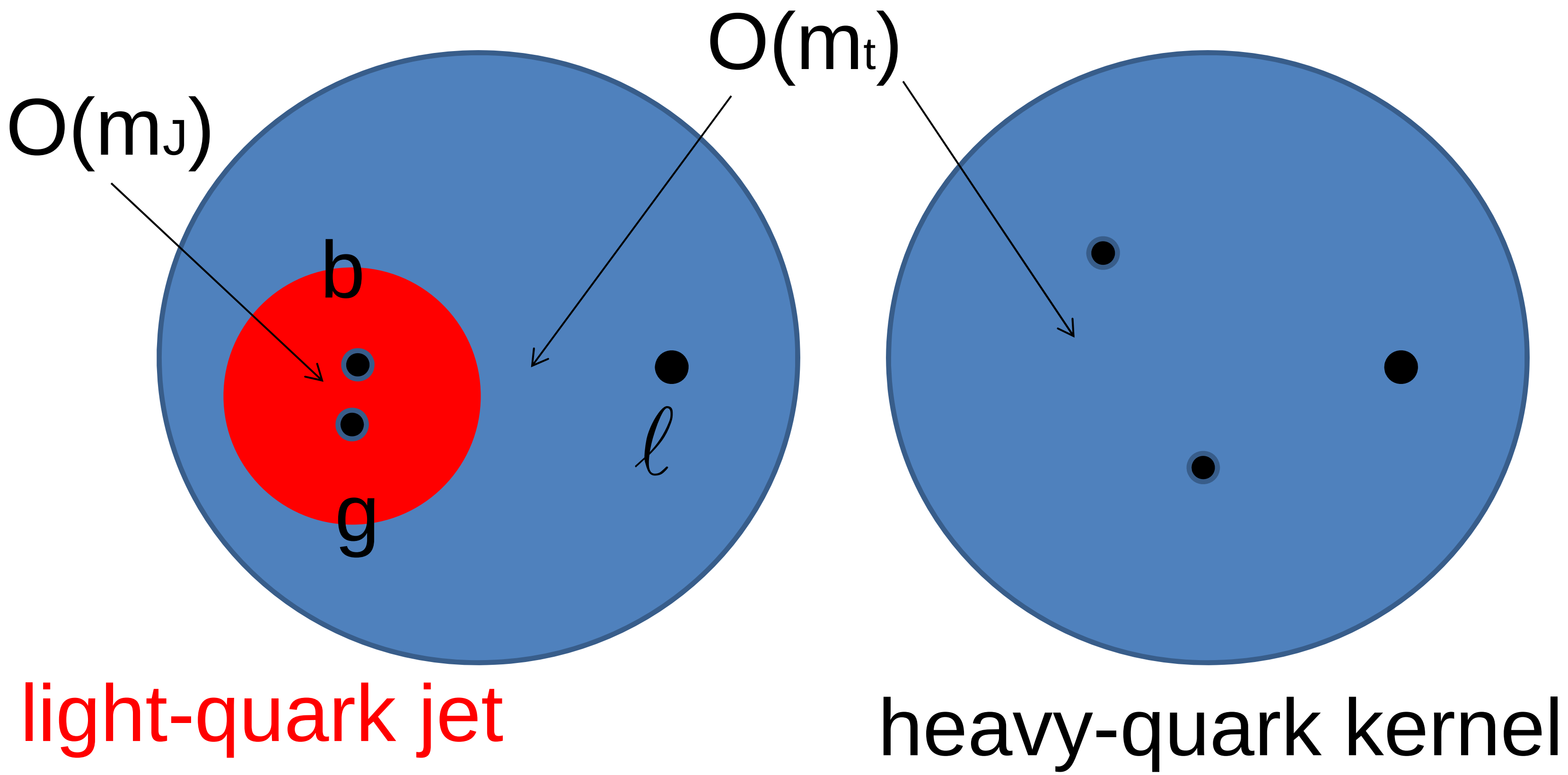
Chirality vs helicity

- BSM heavy particles decay into boosted tops
- Chirality of BSM physics revealed by helicity of boosted tops
- How to determine helicity of boosted tops?
- Polarization of rest top determined by angular distribution of decay products
- Propose to measure jet substructures---energy profiles depend on helicity
- Require no b-tagging, W reconstruction

Review articles: F.-P.Schilling (2012), W.Bernreuther (2008), etc.

Scale hierarchy $E \gg m_t \gg m_J$

- The two lower scales m_t and m_J characterize different dynamics, which can be factorized



Spin decomposition and boost

- Spin projector $w_t = \frac{1}{2}(\mathbf{1} + \gamma^5 \not{s}_t), \quad \bar{w}_t = \frac{1}{2}(\mathbf{1} - \gamma^5 \not{s}_t),$

Unpol. = spin up + spin down

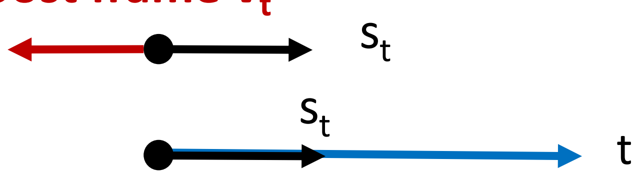
$$(\not{k}_t + m_t) = (\not{k}_t + m_t)w_t + (\not{k}_t + m_t)\bar{w}_t$$

- **Easier to work in rest frame of top first, and then boost**
- **Helicity** (+ or R, - or L) and **Boost** from Lorentz transformation

$$s_t^\mu = (0, 0, 0, 1)$$ **Z axis = top spin direction**

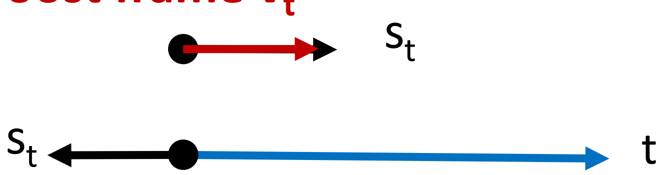
J. Shelton,
PRD 79, 014032 (2009)

Boost frame v_t



Right-handed

Boost frame v_t

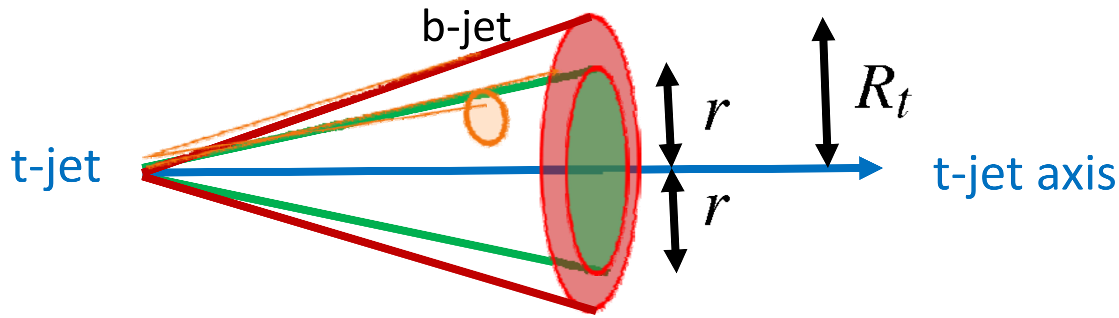


Left-handed

Jet energy profile

Li, Li, Yuan 2013

- Consider a test cone (angle r: 0 < r < R_t) in top-jet. Accumulate the sub-jet energy in the small cone.



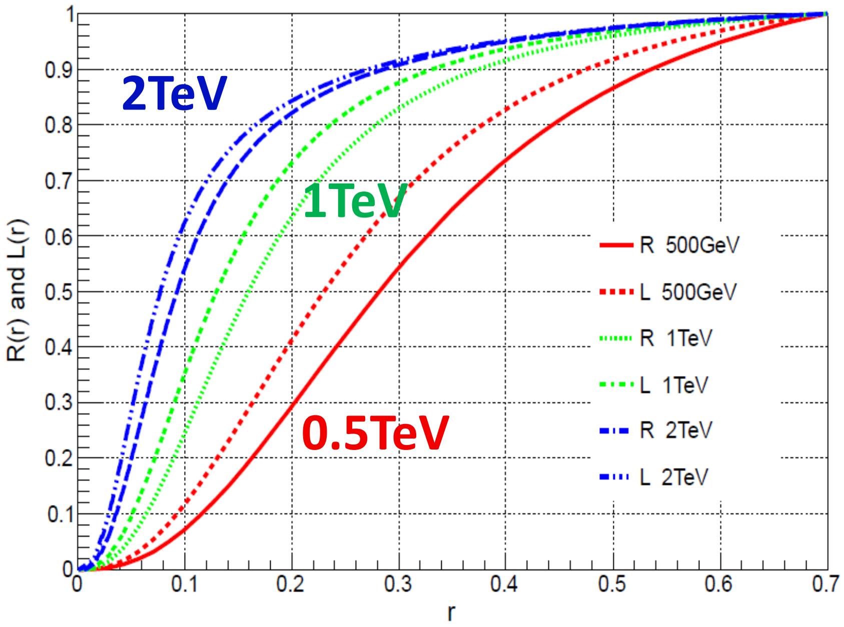
$$\text{Ratio}(E_{J_t}, R_t, r) \equiv \frac{\text{Jet (transeverse) energy in cone } r}{\text{Jet (transverse) energy in cone } R_t}$$

(Jet energy profile)

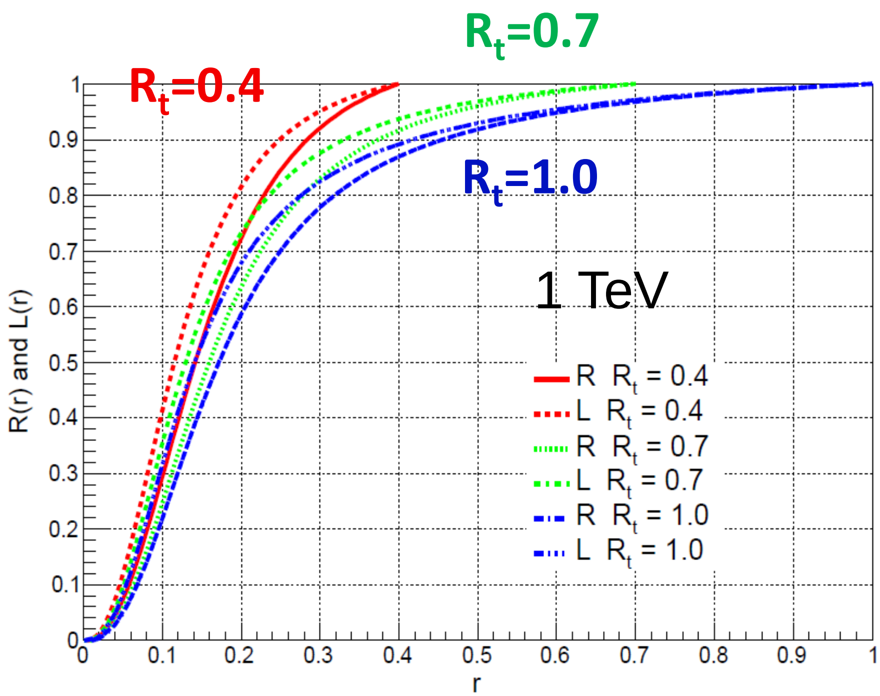
- This ratio describe a "spread" of energy in the small cone r caused by the sub-jet distribution

Top-jet energy profile

Top-jet energy dependence



Top-jet radius dependence



Left > Right tendency (L is faster than R) again.

|L-R| difference decrease as E_{jt} increase.

Top-jet radius dependence is not significant.

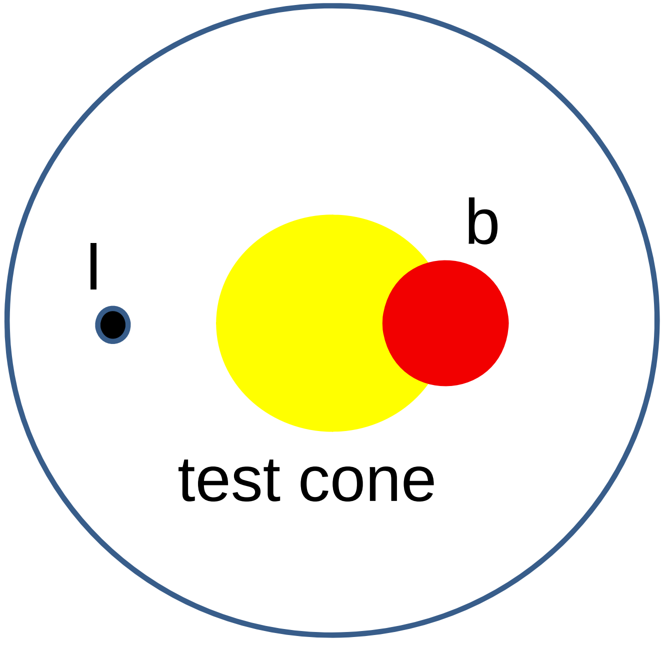
Boosted hadronic tops

Theoretically hard, but experimentally easy

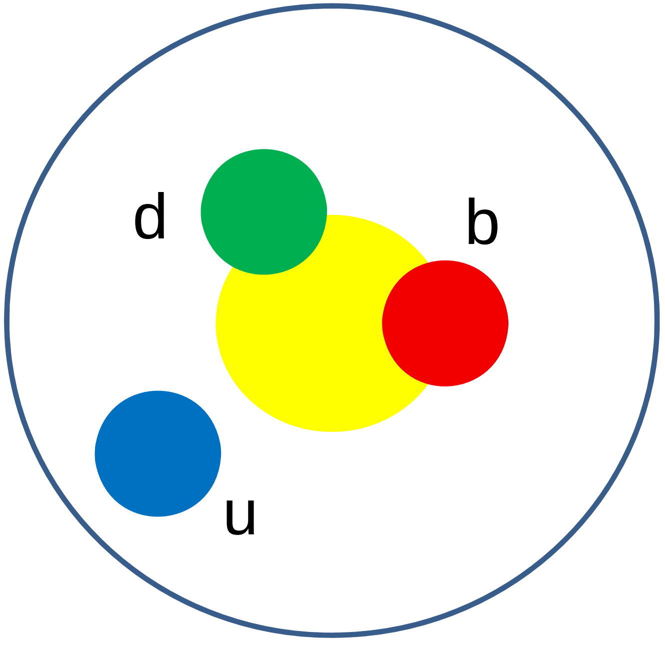
Difficulty 1

- Three-body kinematics in t -> bud
- In semileptonic decay neutrino kinematics is integrated out, basically two-body

$$k_l \sin\theta_l = k_b \sin\theta_b$$

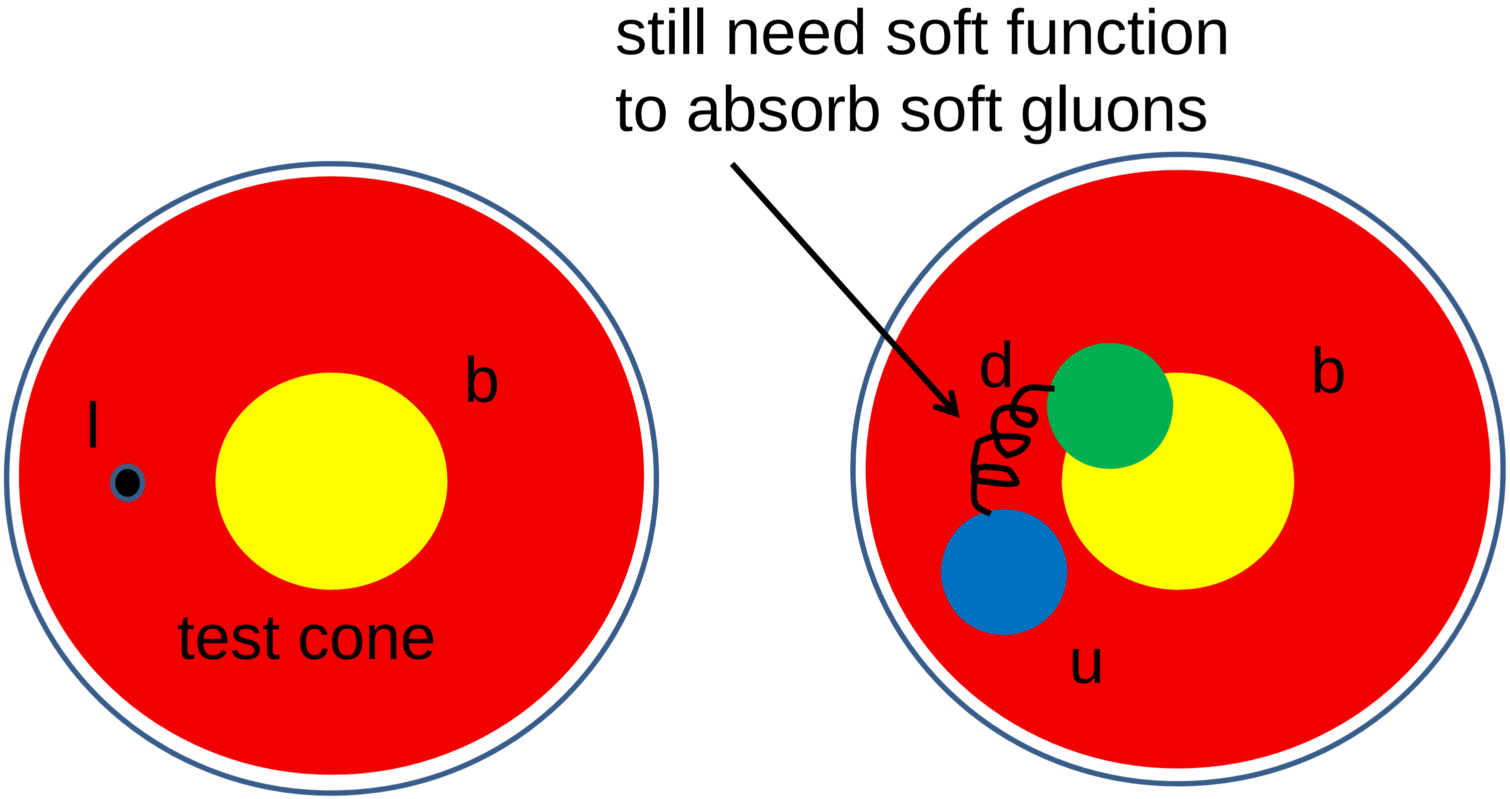


complicated angular relation



Difficulty 2

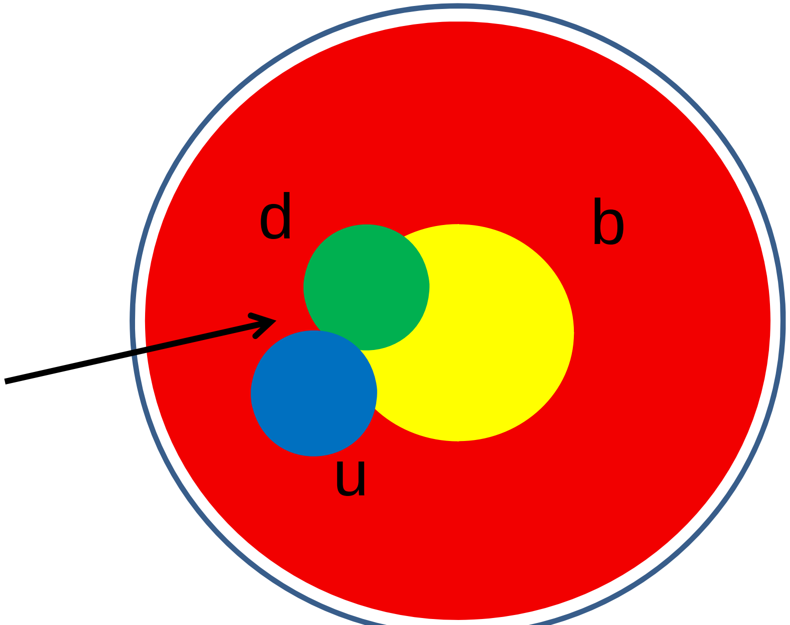
- Treatment of soft gluons
- Consider a fat b jet, which absorbs soft gluons in semileptonic case



Difficulty 3

- Jet merging
- No jet merging issue in semileptonic case
- When subjets overlap, how to count their contribution to test cone?
- Ambiguity to define subjet radii

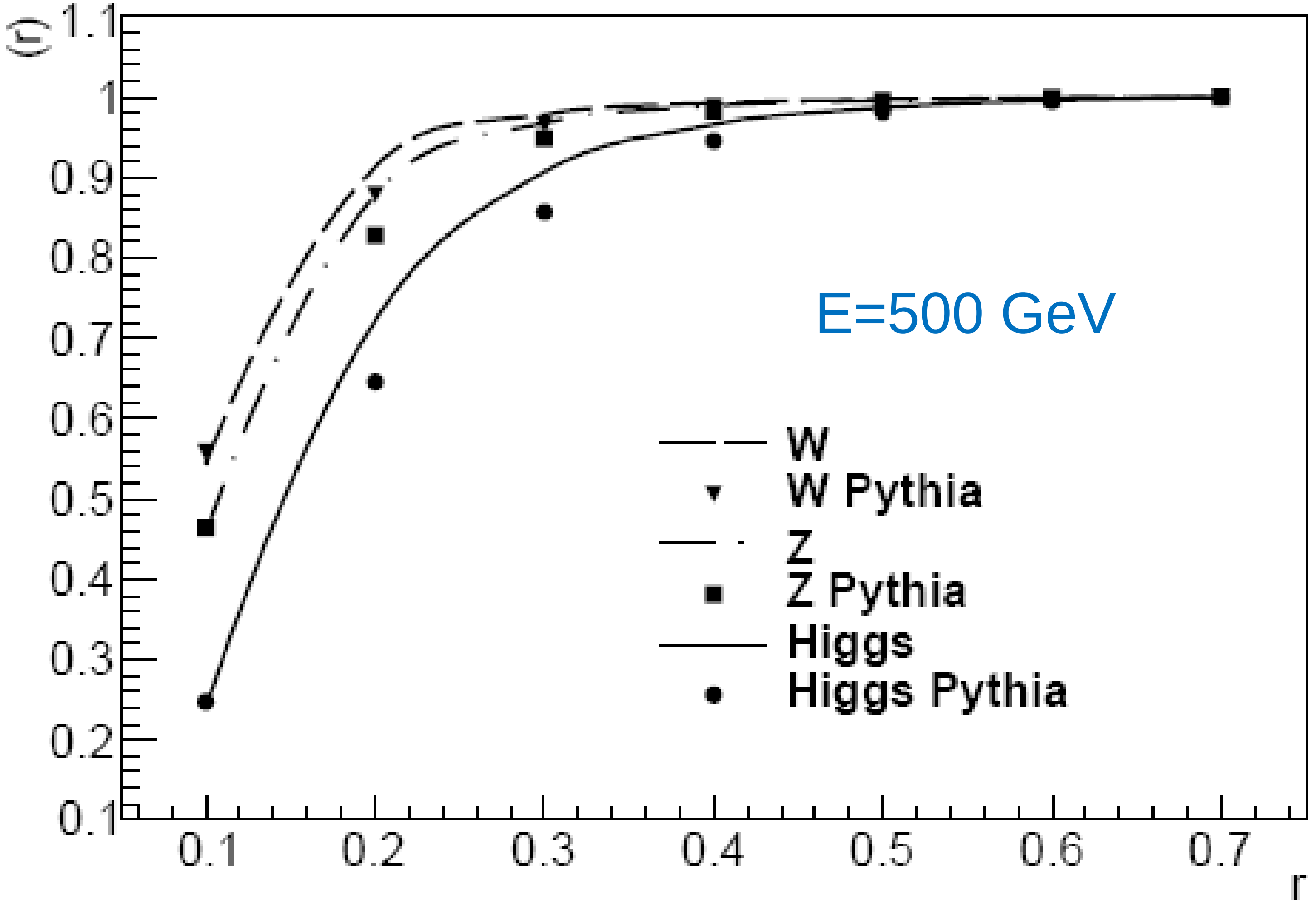
counted as single jet
or two jets



Sequential factorization

- Factorization of top jet into fat W-boson jet, thin bottom jet, and top decay kernel
- Factorization of fat W-boson jet into fat light-quark jet, thin light-quark jet and W decay kernel
- At each step of factorization, handle only two-body kinematics

Heavy-boson jet profiles

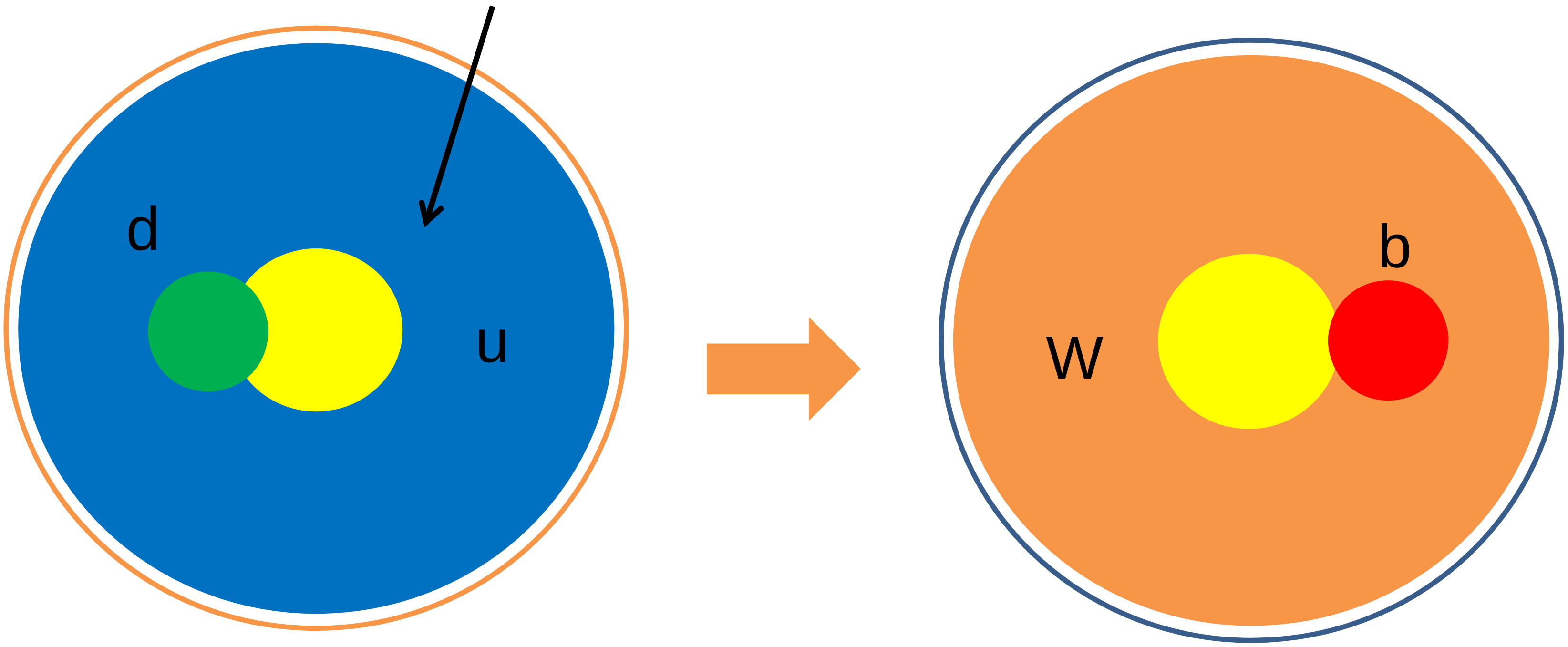


No soft function

- Construct W-boson jet

contain soft gluons

then construct top jet

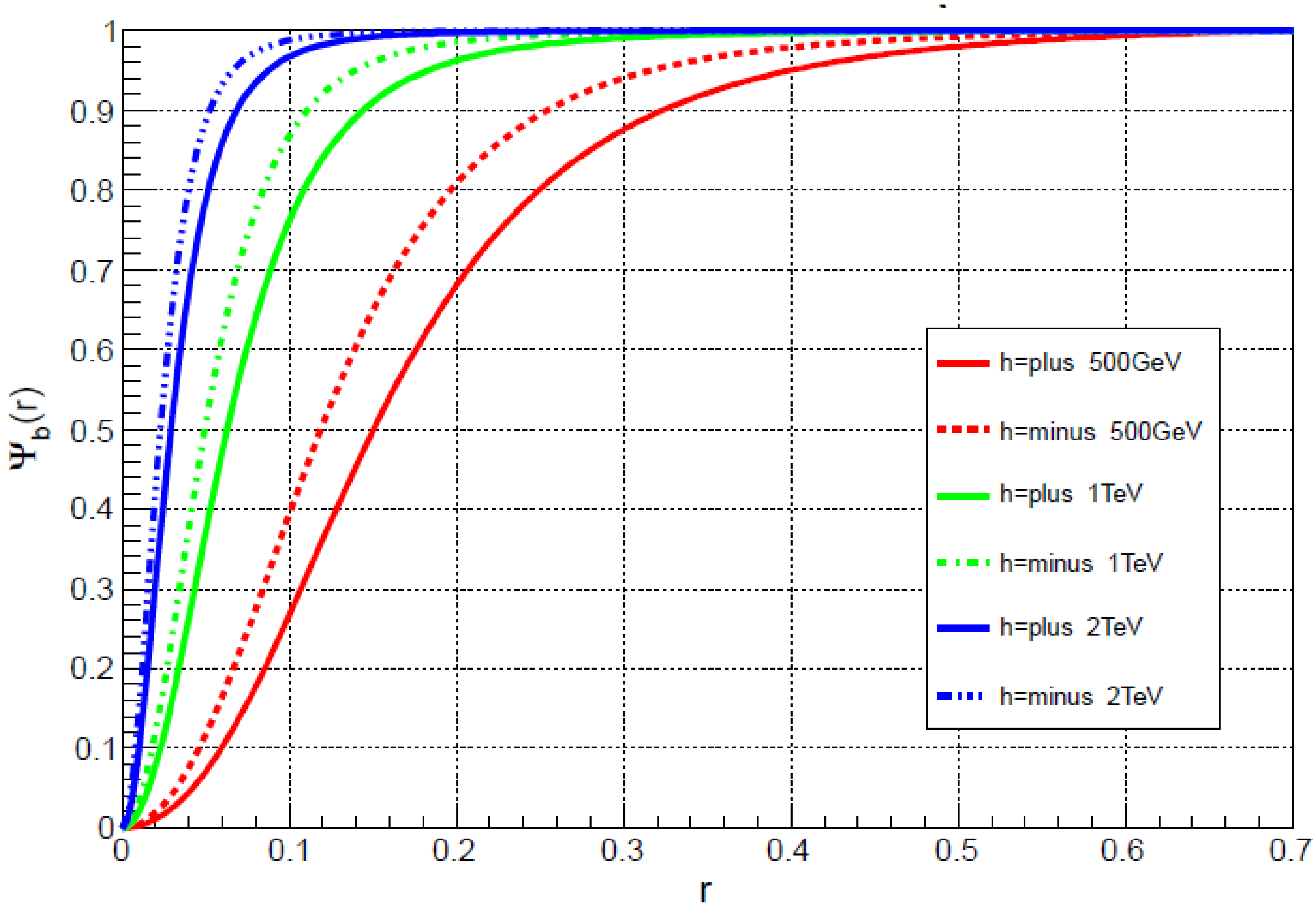


soft gluon exchanges between
b quark and color-singlet W boson
are suppressed

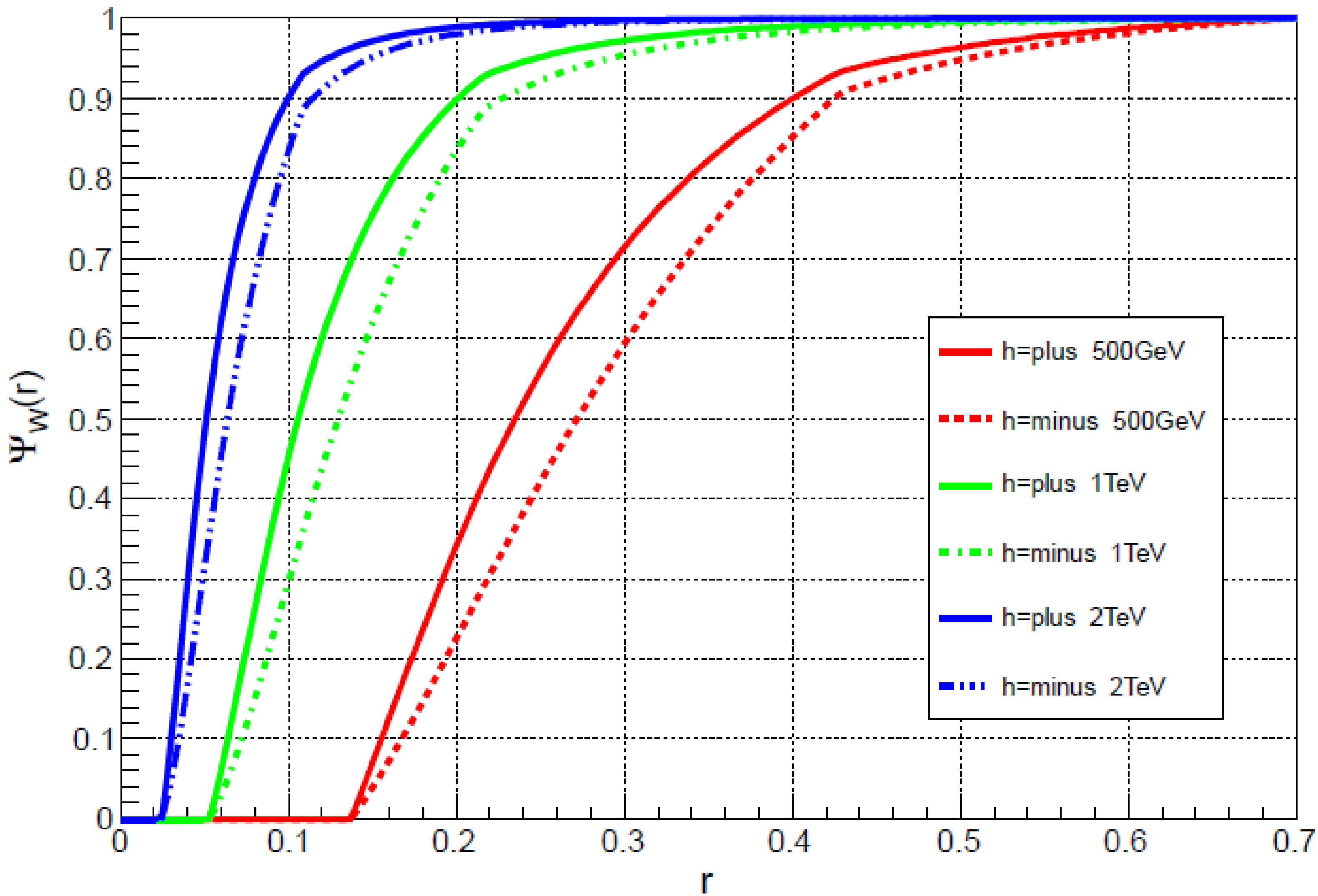
No jet merging

- Up and down jets completely overlap, no jet merging issue
- W-boson jet and bottom jet completely overlap, no jet merging issue
- Fat jet has radius R (top jet radius), and thin jet has radius r (test cone radius, focusing on energy profile at small r)
- No ambiguity to define jet radii
- Double counting of soft gluons is negligible at small r

Top jet energy profiles

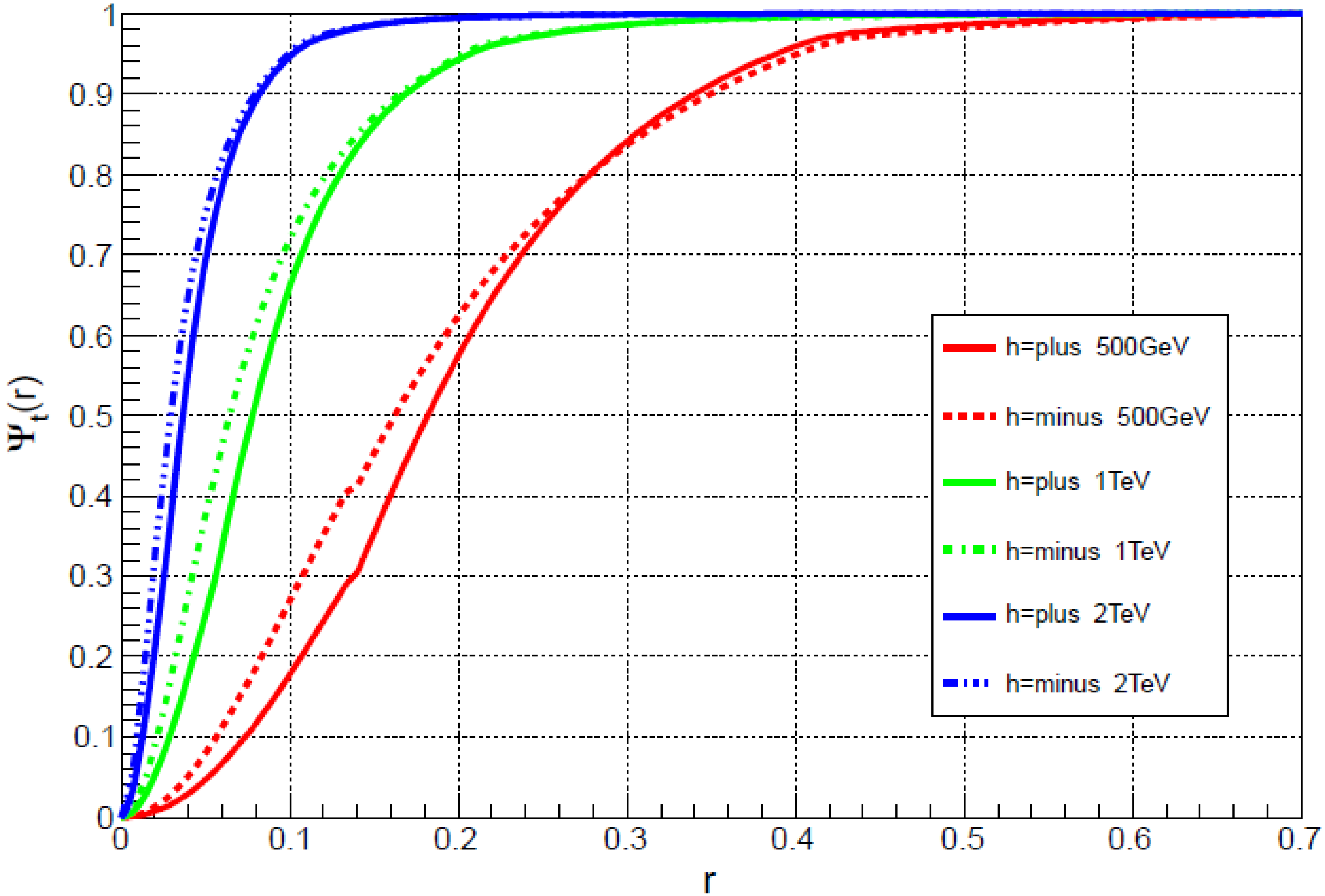


bottom jet contributes more to left-handed top
similar to energy profiles of leptonic top jet



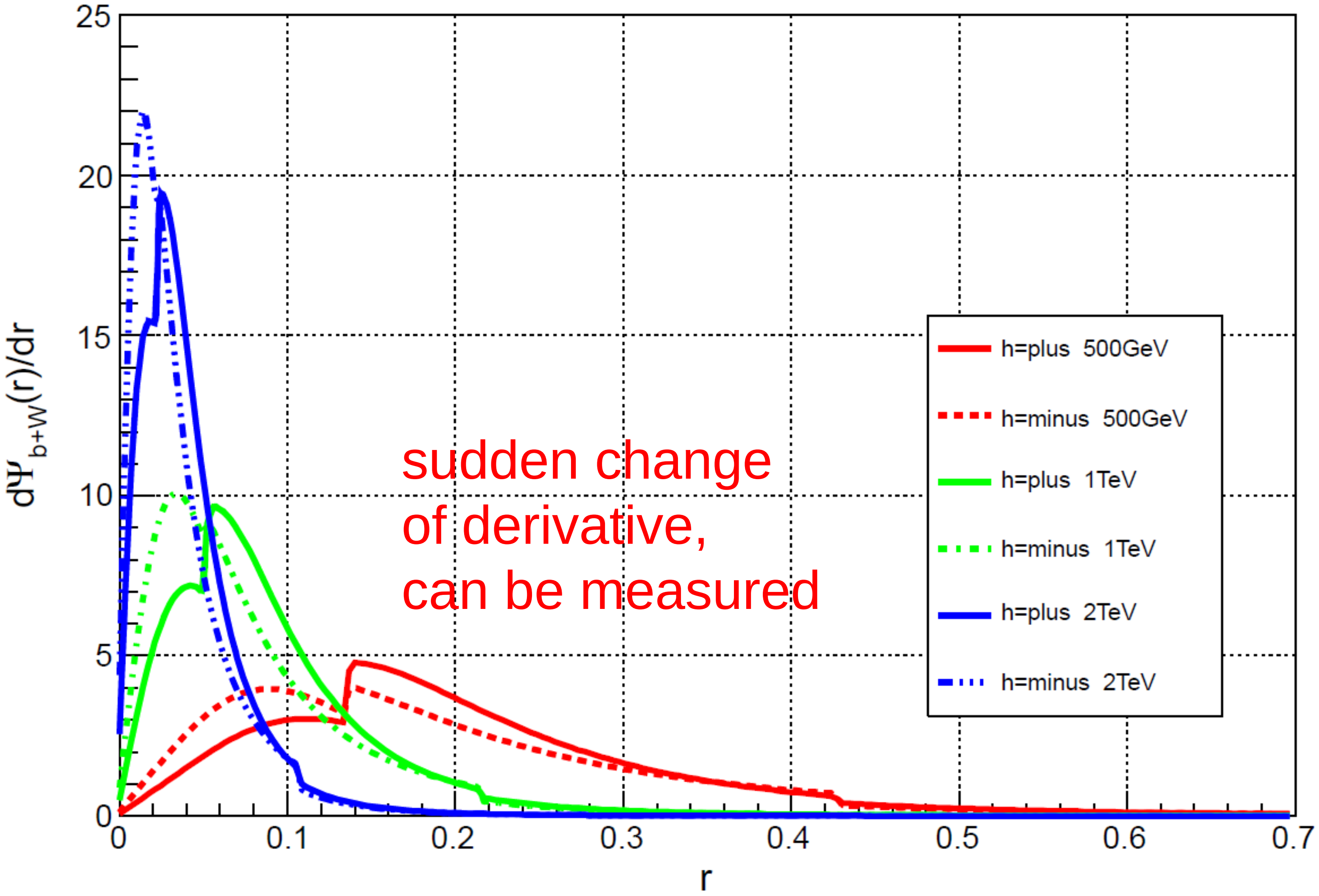
W jet shows obvious dead-cone effect, and contributes more to right-handed top

Energy profiles of hadronic top jet



due to W jet contribution, right-handed profile shows obvious kink at small r

Derivative of energy profiles

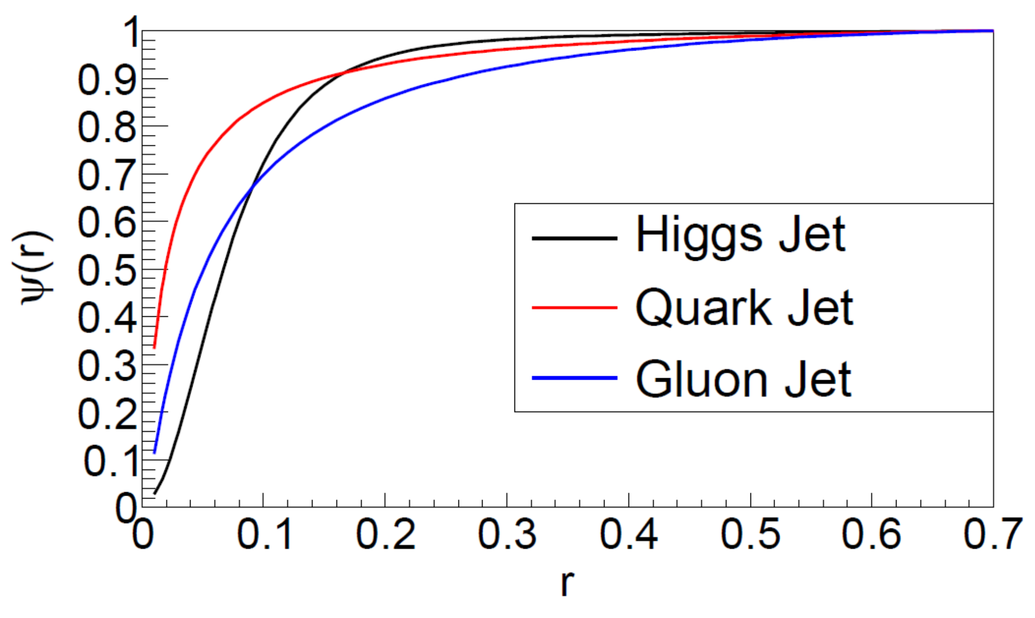


Observations

- Jet substructure is useful for identifying boosted heavy particles.
- Can be studied by PQCD factorization and resummation technique.
- Found different helicity/chirality dependence of jet substrucuture for polarized top jets.
- Energy profile of L(helicity -) top jet is larger than R(helicity +) top jet.
- Need thousands boosted tops (as integrated L = 25 fb^-1)

Conclusion

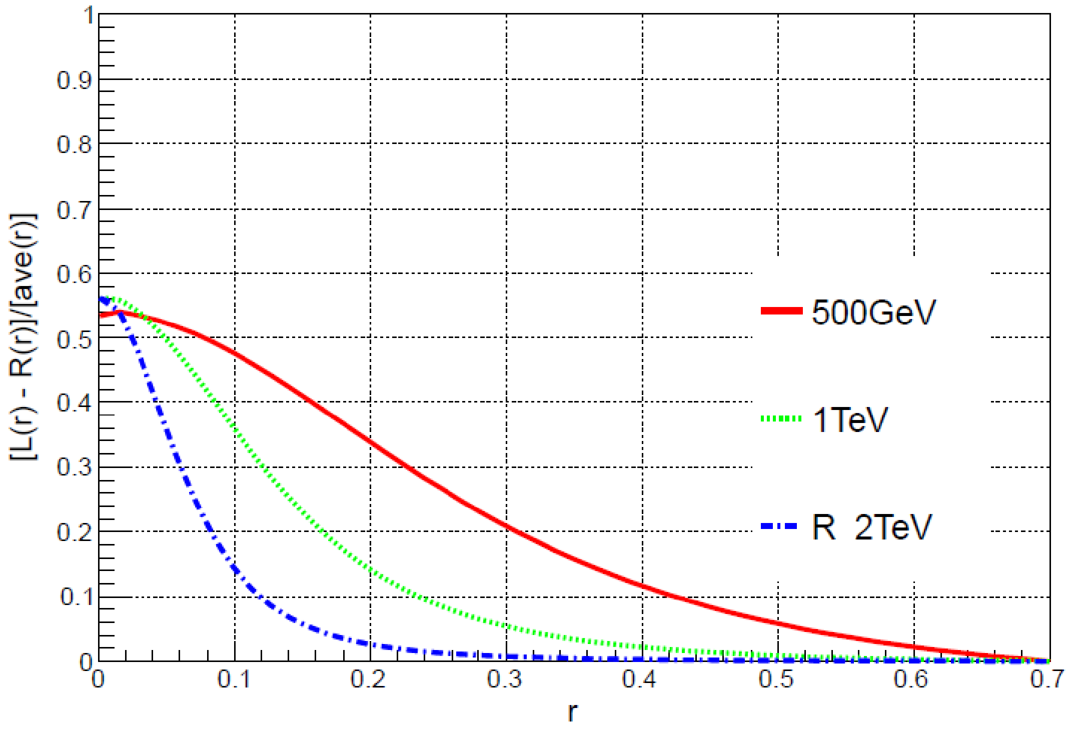
- Have analyzed light-quark jet, gluon jet, Higgs jet, W-boson jet, leptonic top jet; show smooth energy profiles with different slopes
- Only hadronic top jet shows energy profile with kink so far
- Right-handed top shows more obvious kink
- Help particle identification



Back-up slides

L-R difference

Ratio of (L-R)/average, average=(R+L)/2



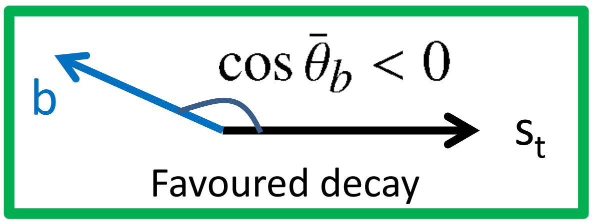
- L-R difference is large at small r region
- (L-R)/average is about 30(10)%, at r=0.1 for 1(2)TeV top jet.
- |L-R| deference decrease as E_{jt} increase again.

Discussion

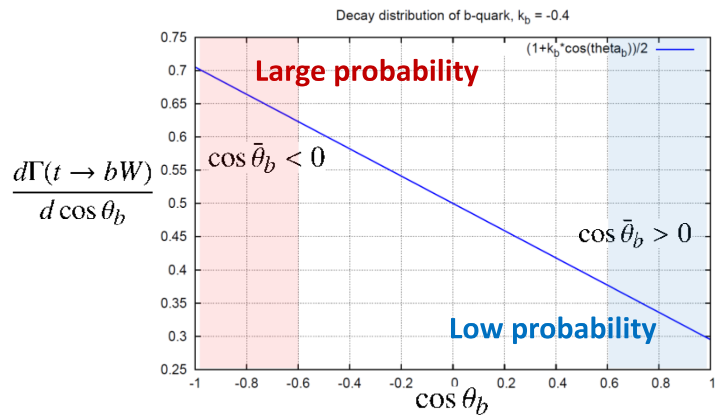
- Why **Left(h=-)** is larger than **Right(h=+)** ?

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_b} = \frac{1}{2}(1 + \kappa_b \cos\theta_b)$$

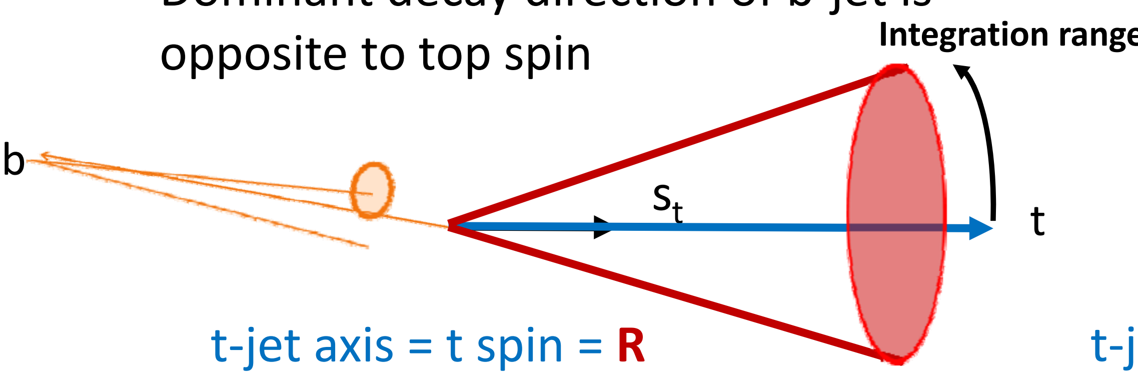
κ_b : b-quark's spin analysing power = **- 0.4**



→ Angular distribution obeys V-A interaction

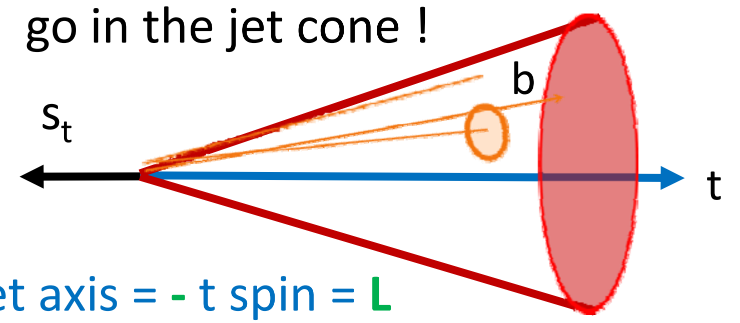


- Dominant decay direction of b-jet is opposite to top spin



t-jet axis = t spin = **R**

L has a larger chance to go in the jet cone !

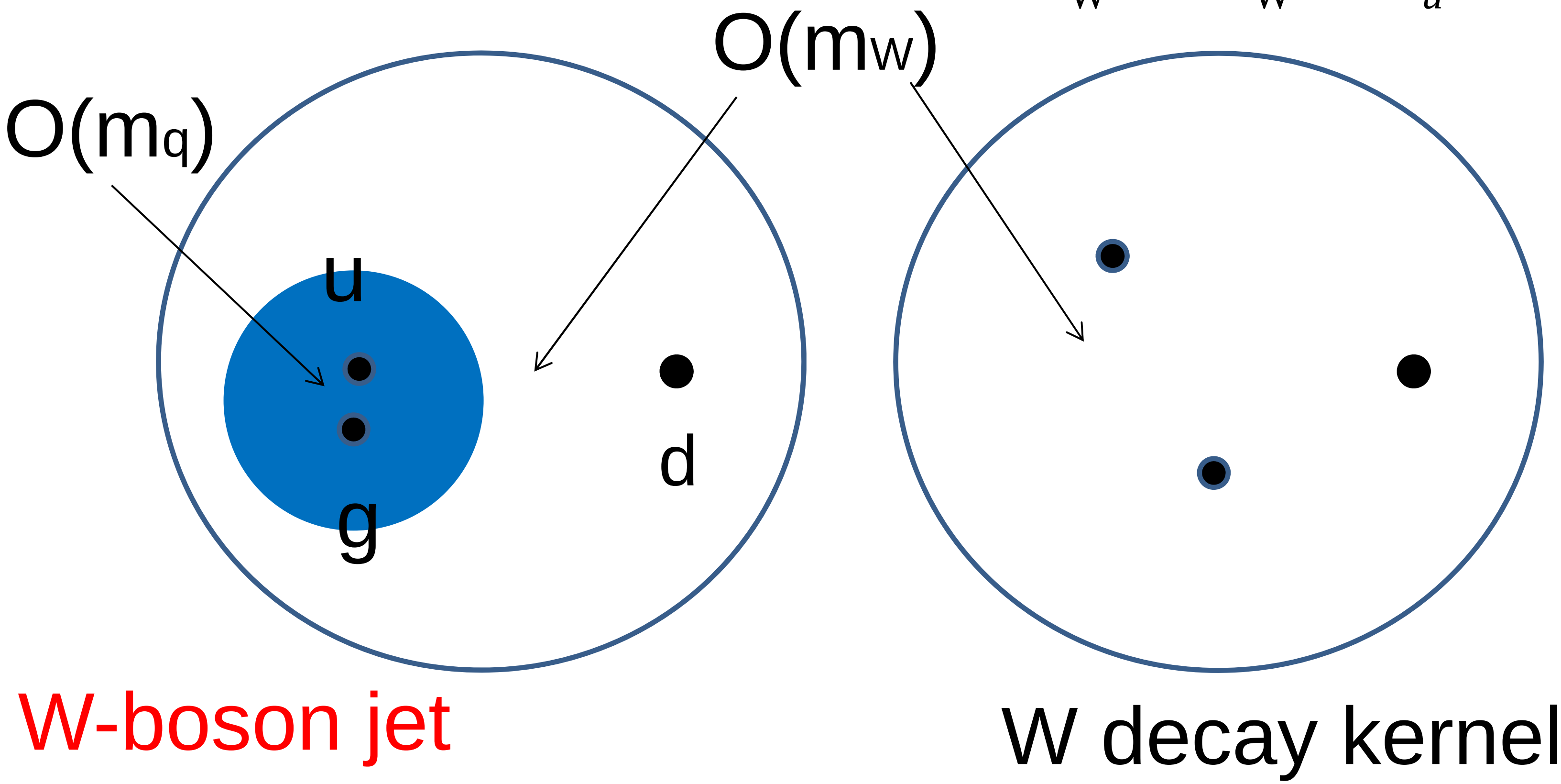


t-jet axis = **-** t spin = **L**

Scale hierarchy $E_{J_W} >> m_W >> m_q$

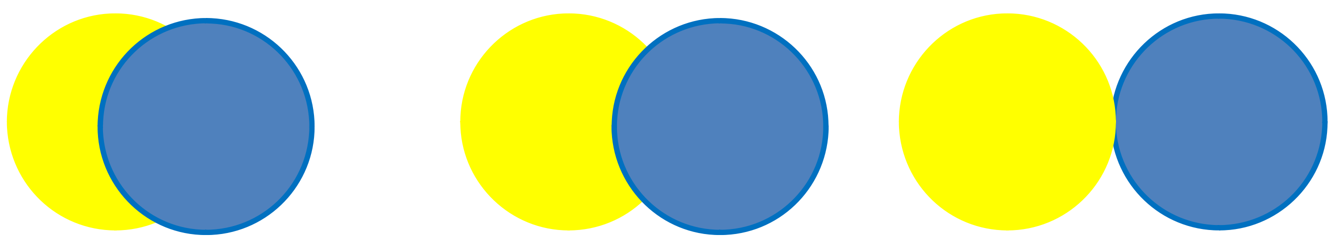
- The two lower scales m_W and m_q characterize different dynamics, which can be factorized

$$J_W = H_W \otimes J_u \otimes J_d$$



Contribution to test cone

- As integrated over polar angle of thin jet, how distant can it be still regarded as contributing to test cone?
- If contributing, whole energy of thin jet contributes; do not calculate partial energy

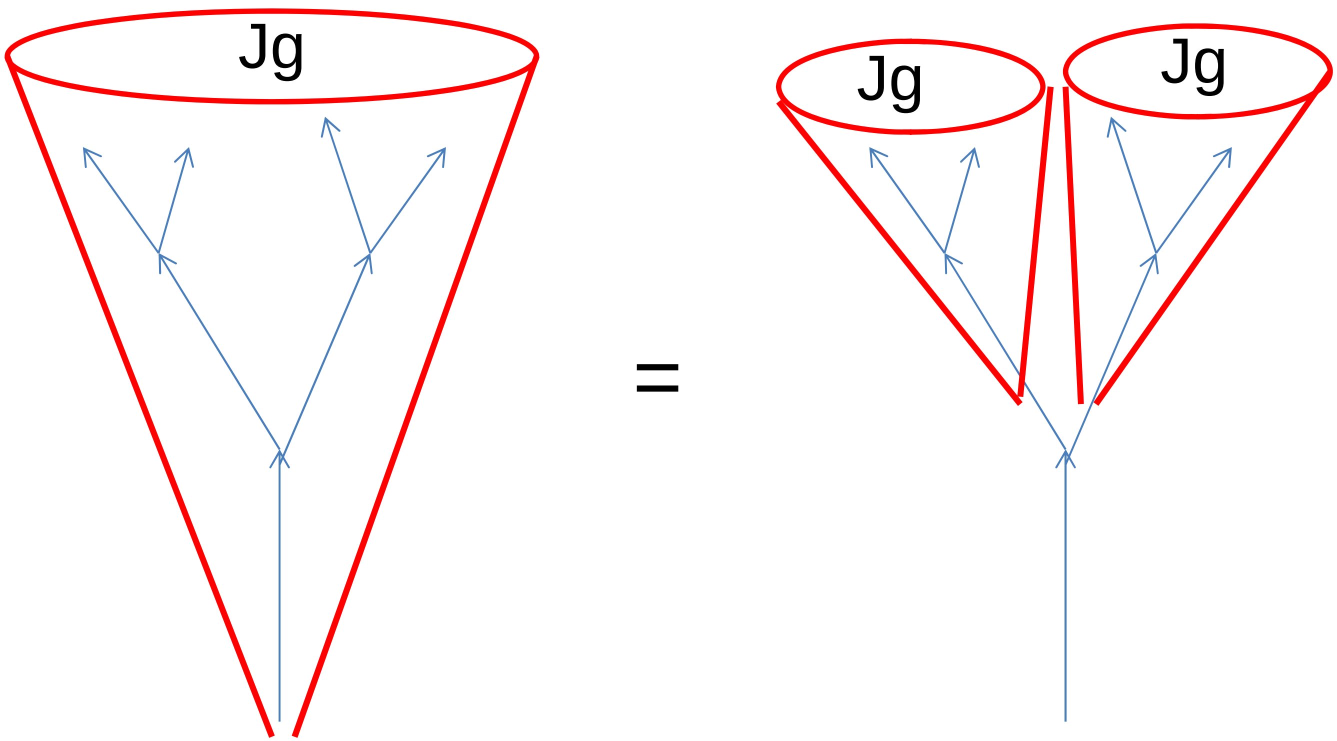


$d=r$	$r < d < 2r$	$d=2r$
yes	?	No

- Calibrate it by gluon jet energy profile

Gluon jet energy profile

- LHS: original gluon jet
- RHS: Factorization into two sub-jets
- Energy profiles in these two schemes equate



d=1.7r

- Energy profile from factorization into two sub-jets coincides with profile of gluon jet